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PUBLIC KNOWLEDGE PARTNERSHIPS IN EUROPEAN RESEARCH PROJECTS AND KNOWLEDGE CREATION ACROSS R&D INSTITUTIONAL SECTORS

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Abstract

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Jelcodes:O31,O32

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ABSTRACT

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Keywords: Public private collaboration, EU Framework Programmes, knowledge creation, absorptive capacity, patents.

JEL Classification: O31, O32, L2, I2

1. INTRODUCTION

According to the theoretical and empirical literature, international cooperation in Research and Technological Development (RTD) activities among firms, universities and public administration, that we define Public Knowledge Partnerships (PKPs) may be a relevant instrument of knowledge transmission. In the Europe, public knowledge partnerships are considered as one of the means to achieve the European Research Area whereby, pooling Member States' resources, it is possible to create the necessary critical mass to face the current challenges posed by scientific and technological research (Luukkonen, 2000; Georghiou, 2001; Caloghirou et al., 2001). More generally, they represent an unconventional and internationally valued instrument of innovation policy (Soete, 2007).

RTD joint projects funded under the European Union's Framework Programmes for research and technological development (FPs) are an example of public knowledge partnerships. This kind of public knowledge partnership assumes an international dimension, which, alongside the multi-sectorial one, confers them a particular role and relevance for knowledge creation and diffusion.

Several studies have focussed on the characteristics of cooperation activities started as a result of FPs or on the performance of such programmes (for a review, see Di Cagno et al., 2014).

However, to the best of our knowledge, no study has focussed on the possibly different impact of public knowledge partnerships on knowledge creation across different R&D institutional sectors[1]. This paper aims at filling this gap by building on the literature investigating the advantages and risks involved in cooperation between companies, governments and universities (for a review see, Foray and Lissoni, 2009). In particular, we test whether FPs public knowledge partnerships affect the innovation capability (measured by patents) of a country, whether this impact depends on domestic innovation and absorption capacity and whether there are differences in the effectiveness of interaction mechanisms between internal innovation drivers and participation in FPs across R&D institutional sectors.

[1] By institutional sectors, or R&D institutional sectors, we refer to the four institutional sectors of performance of R&D activities: business enterprise (BES), government (GOV), higher education (HES), and the private non-profit (PNP), that is the overall actors involved in innovative activity (Eurostat, 2014). For the purposes of our analysis, and to harmonize Eurostat and Annual Reports of the European Commission (EC) data, we have joined PNP institutions with GOV sector. As well Eurostat in an update of the sector allocation methodology for patent statistics opted for a combination of the previous public and private non-profit institution sectors into a single "Government sector or private non-profit" sector.

This topic is of great relevance in the light of the high and increasing share of the EU budget devoted to finance collaborative research and on the increasing emphasis on the benefits of public-private and international partnerships for innovation (European Commission, 2010). In particular, the international and inter-sectoral character of FPs raises a series of questions on what the pre-conditions are for allowing these projects to contribute most effectively to knowledge generation across countries and sectors. The attempt to estimate the differential benefits accruing to the different R&D institutional sectors (private companies, public research centres and universities) when taking part in collaborative projects helps shedding light on their incentives to participate and on the effectiveness of the composition of the programmes in terms of their ability to contribute to new knowledge generation. Overall, therefore, the paper aims at informing the theoretical and policy debate on the costs and benefits of public private partnerships by providing new empirical evidence on the mechanisms favouring/impeding their effectiveness for new knowledge generation in the case of European Framework Programmes.

The paper is structured as follows: Section 2 illustrates the features of knowledge creation in Public Knowledge Partnerships and introduces the specific case of the EU framework programmes for research and development; Section 3 discusses the research hypotheses and introduces the estimated equations; Section 4 describes the data and reports descriptive statistics; Section 5 presents the results of the empirical analysis; finally, Section 6 concludes.

2. KNOWLEDGE CREATION IN PUBLIC KNOWLEDGE PARTNERSHIPS AND THE CASE OF EUROPEAN UNION'S FRAMEWORK PROGRAMMES

In this paper, we refer to cooperation activities between companies, universities and research organisations supported by the public sector in order to create, share and diffuse knowledge as "public knowledge partnerships (PKPs)" thus highlighting their three basic components: the public context in which they take place, their intended goal and their characteristic inter-institutional context. Research and technological development (RTD) policies undertaken under the umbrella of Framework Programmes financed by the European Community are an example of PKPs. Such partnerships are not a European exclusivity. They are actually relevant, also from a historical perspective, in other contexts such as the United States and Japan. However, they add to the heterogeneity in the nature of participants, typical of PKPs, another source of heterogeneity, i.e. their international character.

European Union's Framework Programmes for research and technological development (FPs) may be considered as an extension of the more conventional research joint ventures between businesses operating in the research and technological development sector (Hagedoorn et al., 2000 and 2002; Hemphill and Vonortas, 2003, Branstetter and Sakakibara, 2002; Hayashi, 2003; Bettina, 2014) and the mechanisms generating innovation through knowledge transfer resemble those discussed in the literature on social networks and knowledge creation (see among others Inkpen and Tsang, 2005; Ozcan, and Eisenhardt, 2009 and for a review Nieves and Osorio, 2013). This literature stresses how access to a network is a necessary but not sufficient condition to acquire the knowledge it contains since new knowledge creation requires the ability to recognize and assimilate valuable knowledge offered by the participants to the network (Inkpen and Tsang, 2005).

There are, however, a series of specificities that characterise knowledge transfer within FPs that are linked to their multisectoral and international character involving a high degree of heterogeneity in the participants' knowledge bases and objectives.

Actors such as businesses, universities and research organisations from different EU countries compose the three traditional institutional sectors of businesses, government and higher education, which are at the basis of the empirical analysis conducted in this paper.

According to the empirical and theoretical literature (OECD, 2002; Miotti and Sachwald 2003; Laursen and Salter, 2004, Jaumotte and Pain, 2005b; Paier and Scherngell, 2011; Bettina, 2014), the above-mentioned subjects may draw benefits from their participation in public knowledge partnerships, namely: (i) access to complementary skills; (ii) direct access to scientific and/or technological knowledge; (iii) risk and cost sharing; (iv) reduction of the degree of uncertainty inherent in the cognitive process; (v) opportunity to move towards the technological frontier; (vi) political and/or legislative benefits deriving from the success of these inter-institutional cooperation initiatives; (vii) reduction in transaction costs of activities disciplined by incomplete contracts; (viii) access to larger financial resources; (ix) learning from other experiences through access to other institutions' best practices; (x) particularly for businesses, the opportunity to internalise (part of) the spillovers; (xi) particularly for universities, the opportunity to create a channel for the placement of their students and researchers in the labour market. However, inter-institutional cooperation may also give rise to difficulties due to the different types of knowledge

and objectives inherent to private firms, research centres (private and public) and universities (Foray and Lissoni, 2009).

In this context, Public Administration acquires the role of "Bridging institution" by maintaining and strengthening links between the two different systems: University and Industry (Foray and Lissoni, 2010). Public intervention in this field may be justified by a number of factors, such as: (i) the reduction of risks associated to the implementation of research and development policies and, more generally, to the uncertainty linked to this activity; (ii) the opportunity to approximate social and private returns; (iii) the ability to bear the lengthy timeframe of cognitive and innovation processes; (iv) the opportunity to overcome appropriability problems deriving from the presence of spillovers; (v) the reduction of difficulties of coordination of a heterogeneous number of agents; (vi) the development and support to the development of technological standards (Jaumotte and Pain, 2005a).

In the case of RTD joint projects funded under the European Union's Framework Programmes for research and technological development (FPs) there is a further element which might foster but also limit knowledge spillovers: the involvement of partners from different countries and cultures. In particular, the European framework aims at creating a common platform that facilitates personal exchanges and overcomes cultural and linguistic differences hindering the transfer of tacit knowledge (Lundvall et al. 2002). Moreover, European institutions may reduce the differences in the national institutional systems. The performance of international innovation cooperation depends upon the rate of homogeneity of countries involved in terms of innovation capability and absorptive capacity: the richest more innovative countries have high levels of both, other less developed countries may only have the absorptive capacity (Freeman, 1987; Nelson, 1993; Fagerberg et al., 2007; Castellacci, 2008, Lundvall et al., 2009). Hence, the European projects may allow the collaboration by overcoming the structural gaps in innovation capabilities. Finally, according to the characteristics of sectors and the nature of their cooperation above mentioned, universities seem to have an international cooperation propensity greater than that of the business sector (Scherngell and Barber, 2011). However, through a structure of incentives promoting cooperation between universities and private enterprises, FPs aim at overcoming the barriers that might exist between the two actors due to their specific cultural models and diversity in objectives.

Although several studies have analysed the organization, the type of cooperation or the overall performance of these programmes (Luukkonen, 2000 and 2002; Caloghirou et al., 2001; Arnold et

al., 2005; Arranz and De Arroyabe, 2006 and 2007; Paier and Scherngell, 2011), we are not aware of any study directly aimed at investigating the role of these projects in favouring innovation through knowledge creation across R&D institutional sectors.

This paper aims at filling this gap, thus contributing to the rich literature, mainly at micro (firm) level, on the innovation impact of knowledge transfer within networks. In particular, this work takes simultaneously into account the diversity in the nature of participants in FPs (private companies, universities and research centres) and their international character. In this context, it gives particular attention to the role played by "absorption capacity" in facilitating knowledge transfer and to the heterogeneity in the relationship between participation in the network and innovation across R&D institutional sectors.

3. RESEARCH HYPOTHESES AND EMPIRICAL SPECIFICATION

In the empirical analysis, in order to assess the performance of FPs on the creation of new knowledge, we adopt the theoretical framework of the knowledge production function (KPF) as outlined initially in Griliches's work (1979)[2]. In spite of its highly simplifying assumptions, the KPF has been widely exploited and estimated in the context of different streams of literature (innovation economics, new economic geography, the new endogenous growth theory) leading to positive results (Furman et al., 2002). In this study (as it is standard in the literature) new knowledge is proxied by patents. An issue with the use of patents in the context of this work is that the business sector, the government sector and higher education institutions may have different objectives and methods to protect new knowledge. For example, firms may be interested in the value of patents (rather than the simple number) and/or may prefer to use "trade secrets" rather than patent protection to avoid being imitated by their competitors[3]. Such strategies may be very different from those pursued by the government sector or by higher education institutions. However, the cross-national and cross-sectoral dimension of our data set does not allow to handle

[2] For empirical analyses using the KPF see, among others, Hausman et al. (1984), Hall et al. (1986), Blundell et al. (1999), Bloom et al. (2013) at industrial and entrepreneurial level; Jaffe (1989) at the institutional level; Meliciani (2000), Porter and Stern (2000), Bosch et al. (2005) and Mancusi (2008) at the national and international level.

[3] Some companies aim to develop "fine-packaged patent map" based on the consideration of comprehensive protection so that their patents will tend to be separated into more detailed content in the relative knowledge domain. In this case they would produce more "small" patents. We thank an anonymous referee for pointing out clearly the main differences in the strategies of knowledge protection between companies, government and higher education institutions.

these differences which are a limitation of our study. As explained later, the problem is partly reduced by controlling for sectoral differences in both the propensity to patent and the relationship between participation in FPs and patenting.

Building on the contributions of Cohen and Levinthal (1989, 1990), Lundvall et al. (2002), Jensen et al. (2007), Charlot et al. (2014), Castellacci and Natera (2013), we construct an "augmented" KPF as composed of three *innovation drivers* at three national sectorial levels: business enterprise, government and higher education (see footnote 1)[4].

The first two are the *internal innovation drivers*: R&D intensity and human capital. They are the main resources of a national innovation system. R&D not only generates new information but also enhances the ability to assimilate and exploit existing information (Cohen and Levinthal, 1989). Human capital also works as a creative input and as a factor embodying tacit knowledge. R&D and human capital interact positively due to their complementarity: research expenditures without competences become useless and vice versa, while their integration amplifies their overall impact (Archibugi and Coco, 2004; Antonelli, 2003; Charlot et al., 2014). This joint dynamic interacts also with the cooperation strategy of firms (Correani et al., 2015).

The knowledge strictly inherent to a particular actor or to a national context (local knowledge, both tacit or codified) may be not accessible due to a sort of secret codes or codes of information not particularly clear to outsiders. Thus, the knowledge transmission has to explicit this kind of knowledge by transforming it in general knowledge (Jensen et al., 2007). Thus, the knowledge transmission is not automatic and needs relevant efforts. In this respect, the literature refers to the *absorptive capacity*, namely, "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990, p.128). Within this process, Cohen and Levinthal (1989, 1990) emphasize the relevance of R&D, while Abramovitz (1986, 1994) the role of human capital. According to Castellacci and Natera (2013), the co-evolution of innovative capability and absorption capacity drives the dynamics of national innovation systems. This leads to our first hypothesis: HP.1 *the innovation process benefits from the complementarity among internal innovation drivers.* This hypothesis is tested by looking at the significance of the interaction between R&D and human capital (see equation 1).

[4] We decided to adopt the national level (rather than the regional one as in other contributions such as Charlot et al., 2014) because the main focus of the paper is on the overall benefits of international public-private partnerships accruing to different R&D institutional sectors and, to the best of our knowledge, there are no available data on patents disaggregated by R&D institutional sectors across European regions.

The third innovation driver is the *network driver* measured by the number of PKPs in FPs. This factor is fundamental for national innovation systems. In fact, not only it helps creating new knowledge but it also facilitates the knowledge transmission that may be intentional (knowledge transfer) or unintentional (knowledge spillover) (Fallah and Ibrahim 2005; Guarini, 2009). In our setting, the network driver consists of the national and international research cooperation among three different actors: companies, research centres (private and public) and universities generating an admixture of codified knowledge - the knowledge produced and transmitted through formal channels - and tacit knowledge - the knowledge produced and transmitted through informal channels - (Johnson and Lundvall, 1994).

Moreover, also in the case of the network driver, its impact on the generation of new knowledge may depend on the intensity of the internal innovation drivers, due to the importance of absorption capacity. Therefore, in the empirical specification, PKPs are added in the knowledge production function as a third innovation driver both in isolation and as an interaction term with human capital.

This leads to our second and third hypotheses: HP.2 *PKPs in European Union's Framework Programmes can stimulate the knowledge process within each country involved* but HP.3 *in order to reap the benefits from international collaboration countries/sectors have to invest in the domestic research community*. Hypotheses 2 and 3 are tested by looking at the significance of total links in FP and of the interaction of this variable with human capital for knowledge generation (see equation 1).

As discussed in the previous section, the interaction between actors with different capabilities helps creating new knowledge especially as result of the complementarities of their skills, but may also give rise to difficulties due to the different types of knowledge and objectives inherent to private firms, research centres (private and public) and universities (Foray and Lissoni, 2009). Most notably, the diversity between University and Industry plays a key role. In terms of the nature of research activity, the former mainly develops basic research and promotes spillovers; the latter aims to exploit the appropriability of knowledge for the commercialisation of the results of the research activity. In terms of the reasons to collaborate, the former collaborates to find resources and ideas for future research resulting in scientific publications, while the latter interacts to obtain advantages in terms of industrial applications and patents (De Fuentes and Dutrenit, 2011). When focussing on patents as a measure of new knowledge creation, companies regard the application-oriented patent as the most important objectives for their commercial benefit while universities

mainly emphasize the basic-science oriented patents as the main objectives; and research organizations focus on the integration platform development of diverse and novel technologies.

This leads to our fourth hypothesis: HP.4 *the impact of the FP on knowledge generation is heterogeneous across R&D institutional sectors.* This hypothesis is tested by estimating the impact of FP on patents separately for the three R&D institutional sectors (businesses, government and higher education). Moreover, in all specifications, we add dummy variables in order to capture time invariant differences across R&D institutional sectors due to measuring the performance of their knowledge creation by the same proxy (patents).

Finally, the composition of FPs might matter for their impact on patents' generation. In particular, considering the higher attention of private firms with respect to universities or public research centres for intellectual property rights and knowledge commercialization, we expect that a higher share of companies in total FPs participants may positively affect the generation of patents. This leads to our fifth hypothesis: HP.5 *the impact of the FP on knowledge generation may depend on the composition of collaborating actors*. This hypothesis is tested by looking at the significance of the weight of business sector on a total country's collaborations (see equation 1).

Summarising, in our sectorial dynamic implementation of the KPF, new economically valuable knowledge depends on the internal drivers (R&D expenditure and human capital), on their interaction, on the network driver, on the interaction between the network driver and human capital and on the composition of FPs:

$$P_{ijt} = RD_{ijt}^{(\beta_1+\vartheta_1 humcap)} \cdot HUMCAP_{ijt}^{(\beta_2+\vartheta_2 rd+\vartheta_3 link)} \cdot LINK_{jt}^{(\beta_3+\vartheta_4 humcap)} \cdot BESW_{jt}^{\beta_4} \cdot POP_{jt}^{\beta_5} \cdot \cdot e^{\sum_i \varphi_i D_i+\eta_{ij}+\gamma_t+h(P_{ijt-1},\phi)} + \upsilon_{ijt} \quad (1)$$

P_{ijt} is new knowledge which is proxied by patents according to the tradition dating back to Griliches's analysis (1990)[5]. RD is R&D over GDP which proxies one of the two internal drivers (the intentional efforts devoted by private companies, public research centres and universities to generate new knowledge). Also in this case, the choice of the proxy is standard in the literature (for a recent example, see Castellaci and Natera, 2013). HUMCAP is our absorptive capacity component proxied by the number of researchers on country population. This proxy is preferred

[5] For a recent discussion on patents as innovation indicators, see Nagaoka et al. (2010).

to broader measures of education (such as the share of people with tertiary education) since we are estimating knowledge generation in terms of patent applications (and not broader measures of performance such as productivity or growth). Moreover, in the case of FPs, participants are researchers from different countries and institutional sectors whose ability to produce new knowledge may depend on the size (and quality) of the domestic research community to which they belong[6]. LINK is the collaborative propensity which is proxied by collaborative links generated by FPs, (absolute number). This proxy is chosen considering the relevance of FP in terms of resourced invested by the European Commission, the international character of the collaborations and the characteristics of involving private companies, public research centres and universities (see also Scherngell and Barber, 2011 and Wanzenbock and Piribauer, 2015). BESW is the weight of the business sector in FPs proxied by the total number of firms participating to FP divided by the total number of participants. Finally, population (POP) is a control variable. We account also for the complementarity between innovative efforts and human capital ($\vartheta_1$and ϑ_2 parameter) and between the collaborative propensity and human capital (ϑ_3 and ϑ_4 parameter). D_i are dummy variables capturing sectorial specific effect, η_{ij} are fixed effects, γ_t time effect and v_{ijt} is a random component. The term $h(P_{ijt-1}; \phi)$ is a function parameterizing the way past patents are affecting the current value. The γ_t parameter shows, among others, the effects of the economic cycle or variations in the propensity to patent connected to institutional changes different from v_{ijt} (not changing over time).

The estimated equation may be expressed in a nonlinear count data panel model (or log-linear model) with the following conditional mean:

$$E(P_{ijt}|x_{ijt}, \eta_{ij}) = exp\left(\beta_1 rd_{ijt} + \rho_1 rd_{ijt} \cdot humcap_{ijt} + \beta_2 humcap_{ijt} + \rho_2 humcap_{ijt} \cdot link_{jt} + \beta_3 link_{jt} + \beta_4 besw_{jt} + \beta_5 pop_{jt} + \sum_i \varphi_i D_i + \eta_{ij} + \gamma_t + h\left(P_{ijt-1}, \phi\right)\right) \quad (2)$$

where *rd*= ln(RD), *humcap* = ln(*HUMCAP*), *link* = ln(*LINK*), *besw* = ln(*BESW*), *pop* = ln(*POP*), $\rho_1 = \vartheta_1 + \vartheta_2$ and $\rho_2 = \vartheta_3 + \vartheta_4$.

[6] One concern in inserting in the same regression R&D intensity and the share of researchers on total population is that they might be highly correlated. This does not appear to be a problem in our regressions, where they both show up positive and significant. The correlation coefficient between the two variables is 0.72.

We use a version of the Negative Binomial model (NB2, or mean-dispersion model, Cameron and Trivedi, 2013) to estimate equation (2) that allows both for correlated fixed effects and dynamics. Its variance under the specification here used is:

$$V(P_{ijt}|x_{ijt},\eta_{ij}) = exp(x'_{ijt}\beta + \eta_{ij}) + \alpha[exp(x'_{ijt}\beta + \eta_{ij})]^2 \quad (3)$$

where the parameter α is a measure of "over-dispersion", relaxing the Poisson restriction that the mean equals the variance (α=0*)*. We use the "pre-sample mean scaling" (PSM) method of Blundell et al. (1999) to control for unobserved heterogeneity or individual sectorial specific effects using past observations of patenting behavior (from 1977 to 1993) to replace fixed effects η_{ij}. This relaxes the strict exogeneity assumption underlying the approach of Hausman et al. (1984). It also permits to introduce dependence over time in P_{ijt}. The PSM method is just a moment based estimator of:

$$E(P_{ijt}|x_{ijt},\eta_{ij},P_{ijt-1}) = h(P_{ijt-1},\phi)\exp(x'_{ijt}\beta + \beta_0^* + \theta ln\bar{P}_{ij}) \quad (4)$$

where $\bar{P}_{i,j} = (1/TP)\sum_{r=0}^{TP-1} PAT_{i,j,i0-r}$ is the pre-sample mean of P; TP is the number of pre-sample. In (4) we also account for potentially important feedback effects and introduce dynamics as in Crepon and Duguet (1997) and Cameron and Trivedi (2013) where the function $h(p_{ijt-1},\phi)$ parameterizes the dependence of the conditional mean on lagged values of P_{ijt}. In our approach $h(P_{ijt-1};\ \phi) = exp(\phi 1[P_{ijt-1}> 0])$, where 1[**.**] is the indicator function. We label this dummy variable D.Patents[7].

4. DATA AND DESCRIPTIVE STATISTICS

Institutional sectors data (BES, GOV, HES)[8] on Research and Development expenditure in real terms (2000 prices and PPS), Researchers (full time equivalent) and Patents (applications to the European Patent Office for priority date) are sourced from the EUROSTAT, as data at the national level: Population and GDP in real terms (2000 prices). Whereas data on joint research projects derive from the Annual Reports of Framework Programmes for Research and Technological Development of the EC Directorate for Research (FPs). FPs are multiannual and include both

[7] In the case of the business sector, due to the higher propensity to patent, we assign the value zero to the dummy variable also for cases in which P_{ijt-1}<= 4 and P_{ijt}<=1 which correspond to "outliers" (5th percentile).
[8] See footnote 1 for the construction of three institutional sectors.

direct and indirect actions: direct actions are implemented by research institutes directly depending on the European Commission (such as the Joint Research Centre) and indirect actions are implemented by Member States participants, classified in the different sectors[9]: business (that encompasses "industry", "enterprise" and "Non-Public-for-profit" beneficiaries), higher education and research. This last category, that we label "government", summarizes research organizations and other participants, with various legal status: "Non-Public-Non-Profit", "Public-For-profit", "Public-Non-Profit"[10].

Table 1 reports the number of participants in FP by country and institutional sector and the number of total and international links (as an annual average over time), while Figure 1 reports the number of participants by institutional sector in the various FP (from FP4 to FP7) [11]. We use this information in the empirical analysis in order to control for the varying composition of private-public partnerships.

The countries with the highest number of collaborations are Germany, United Kingdom, France, Italy and Spain. Coherently with the spirit of the European Policy, the collaborations are mainly international: except for Iceland, the percentage is more than 90 per cent. The volume of collaborations has increased from the fourth (period 1994-1997) to fifth FP (1998-2001), while it has dramatically reduced in the following FPs.

[9] Over the years, the nomenclature for the organizations type in the Annual Reports has changed, so as to require a harmonization procedure with Eurostat data for R&D institutional sectors.

[10]Total number of participants, excluding Human Resources and Mobility activity was of 65,960 in FP6, compared with more than 75,046 of the FP5. These participants were involved, respectively in 5,485 and 12,391 contracts, where a contract corresponds to a funded research project in a given priority area (as Life sciences, genomics and biotechnology for health, Information society technologies and so on, Commission, 2008).

[11] For FP 2007 - 2013, data refer to the period 2007 – 2009. We call the four periods, 1994-1997, 1998-2001, 2002-2006 and 2007-2010, FP4, FP5, FP6 and FP7, respectively, in accordance with EU Framework Programmes nomenclature and their temporal extension.

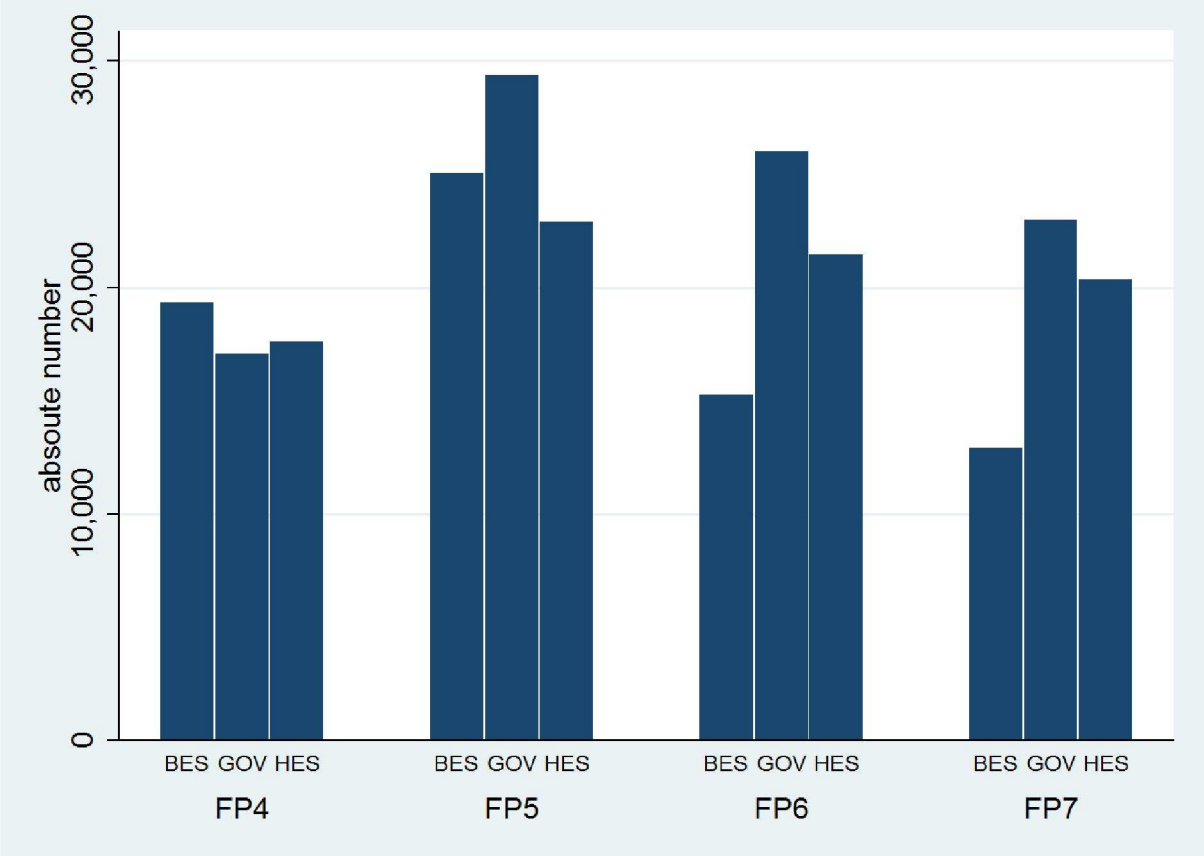
Table 1 Number of participants in signed contracts by countries and institutional sectors and number of links by country, annual average 1994 – 2009

Country	Total participants	SECTOR (%)			LINK (1)	LINK (only international) (2)	(2)/(1) (%)
		BES	GOV	HES			
Austria	405	29,4	37,0	33,6	4041	3865	95,6
Belgium	663	27,5	38,6	33,9	7054	6731	95,4
Bulgaria	76	21,1	51,3	26,3	860	831	96,6
Cyprus	41	24,4	46,3	29,3	389	382	98,2
Czech Republic	183	25,1	48,6	26,2	1925	1862	96,7
Denmark	405	27,4	40,5	32,1	4248	4090	96,3
Estonia	55	18,2	43,6	38,2	558	543	97,3
Finland	375	25,6	41,9	32,5	4195	4008	95,5
France	1900	31,9	49,3	18,8	18197	16372	90,0
Germany	2321	34,8	36,2	29,0	22597	20164	89,2
Greece	579	30,1	40,1	30,1	5706	5392	94,5
Hungary	183	21,3	49,7	29,0	1860	1794	96,5
Iceland	30	20,0	53,3	26,7	365	320	87,7
Ireland	207	25,1	23,7	51,7	2276	2204	96,8
Italy	1541	31,7	39,5	28,9	15220	13891	91,3
Latvia	38	18,4	50,0	31,6	361	351	97,2
Lithuania	42	14,3	54,8	31,0	511	494	96,7
Luxembourg	24	58,3	41,7	4,2	340	331	97,4
Malta	14	21,4	57,1	21,4	187	185	98,9
Netherlands	979	27,4	38,3	34,3	9521	8982	94,3
Norway	294	31,0	43,9	24,8	3139	3005	95,7
Poland	270	15,6	47,0	37,4	2831	2722	96,1
Portugal	314	31,2	39,2	29,9	3386	3252	96,0
Romania	119	16,8	49,6	33,6	1036	1004	96,9
Slovakia	69	15,9	56,5	26,1	799	770	96,4
Slovenia	97	18,6	51,5	29,9	1063	1027	96,6
Spain	1168	31,3	42,0	26,9	11126	10309	92,7
Sweden	601	25,1	28,6	46,4	6883	6568	95,4
Switzerland	419	23,2	31,7	45,1	3958	3837	96,9
Turkey	55	20,0	34,5	45,5	617	605	98,1
United Kingdom	2174	26,3	23,8	49,9	20072	18214	90,7
Total	15641[a]	25,4[b]	42,9[b]	31,7[b]	155321[a]	144105[a]	95,3[b]
		(8.132)	(8.655)	(9.274)			(2.725)

Notes: the sector "HES" encompasses all higher education institutions and the sector "GOV" merges all research and private non-profit institutions. Standard deviation in brackets. [a] sum, [b] mean.
Source: processing of *Annual Reports* data of the European Commission

The collaborations with the business sector have decreased (Commission, 2009), while those with the public sector have increased. In general, in the period 1994-2009, the European average of the percentage of Business sector, Government sector and University are respectively 25%, 42% and 31%. The countries of Eastern Europe have the lowest weight of the business sector.

Figure 1 Participants in Framework Programme (FP) by institutional sector



Notes: the sector "HES" encompasses all higher education institutions and the sector "GOV" merges all research and private non-profit institutions. FP4=1994-1997, FP5=1998-2001, FP6=2002-2006, FP7=2007-2009. See footnotes 9.
Source: processing of Annual Reports data of the European Commission.

The downward trend in participation of companies in FPs has been a concern for the European policy since FP4 was launched (Åström et al., 2012). Many FP-related evaluations concerning this issue highlight the most important administrative and non-administrative barriers resulting in a real burden for preparing the proposal, managing and reporting the project. These barriers, matched with the little chance of getting the project proposals approved, appear to be the main factors inhibiting companies' participation in FPs. Moreover, the main precompetitive nature of the FPs makes them more suitable for academic than industrial research (Protogerou et al., 2013).

Table 2 reports the descriptive statistics of the sectorial variables (patents, R&D intensity, human capital) for the countries considered (*j = 1, ..., 31*) and the period of time here examined (*t = 1994-2009*).

Table 2 Descriptive statistics for countries and institutional sectors, annual average 1994 – 2009

Variable	Patents per million population				R&D intensity (%)				Researchers per 1000 population			
Country	SECTOR				SECTOR				SECTOR			
	ALL	BES	GOV	HES	ALL	BES	GOV	HES	ALL	BES	GOV	HES
Austria	151.917	122.620	0.669	1.660	2.015	1.364	0.121	0.547	2.930	1.877	0.142	0.912
Belgium	122.550	101.512	2.169	9.204	1.831	1.286	0.149	0.396	2.959	1.534	0.216	1.209
Bulgaria	1.647	0.755	0.063	0.064	1.625	0.486	0.990	0.147	1.386	0.178	0.831	0.377
Cyprus	8.765	6.027	0.089	0.862	0.357	0.071	0.166	0.122	0.618	0.135	0.160	0.322
Czech Republic	9.620	6.601	0.351	0.321	2.604	1.624	0.621	0.359	1.745	0.734	0.513	0.495
Denmark	175.404	153.860	1.831	3.767	1.796	1.192	0.182	0.423	4.362	2.440	0.559	1.374
Estonia	9.000	5.450	0.183	0.877	1.526	0.526	0.387	0.684	2.299	0.417	0.553	1.423
Finland	228.514	210.485	3.465	0.599	2.773	1.929	0.321	0.523	7.852	4.421	0.854	2.080
France	119.350	98.219	8.289	1.475	2.023	1.264	0.387	0.372	3.017	1.529	0.480	1.008
Germany	248.792	221.084	5.459	2.078	2.196	1.510	0.312	0.374	3.199	1.875	0.487	0.837
Greece	6.273	2.784	0.189	0.125	0.686	0.202	0.154	0.324	1.359	0.319	0.194	0.834
Hungary	11.655	8.211	0.105	0.166	1.803	0.797	0.486	0.435	1.424	0.459	0.441	0.524
Iceland	83.317	71.300	0.425	1.733	1.830	0.911	0.504	0.413	6.059	2.608	1.663	1.777
Ireland	55.724	40.928	0.375	5.346	1.137	0.779	0.087	0.271	2.404	1.432	0.130	0.837
Italy	68.256	57.719	0.752	0.779	1.153	0.582	0.220	0.351	1.331	0.503	0.276	0.552
Latvia	3.796	2.352	0.163	0.244	0.905	0.306	0.254	0.350	1.414	0.193	0.337	0.884
Lithuania	1.916	0.847	0.166	0.109	1.352	0.242	0.519	0.608	2.224	0.139	0.654	1.436
Luxembourg	160.881	140.844	1.678	0.535	1.587	1.470	0.144	0.023	4.091	3.461	0.667	0.194
Malta	10.692	8.970	0.460	0.312	0.449	0.221	0.035	0.219	0.777	0.253	0.039	0.540
Netherlands	189.555	168.047	7.834	3.558	1.859	0.983	0.277	0.599	2.721	1.264	0.473	0.984
Norway	81.451	69.273	0.563	0.754	1.255	0.703	0.197	0.355	4.414	2.290	0.725	1.400
Poland	2.511	1.437	0.198	0.192	1.161	0.397	0.407	0.357	1.487	0.245	0.316	0.926
Portugal	5.680	3.640	0.168	0.565	1.026	0.375	0.282	0.369	1.993	0.378	0.558	1.057
Romania	0.717	0.394	0.034	0.040	1.346	0.839	0.362	0.153	1.066	0.594	0.293	0.180
Slovakia	3.840	2.657	0.139	0.162	1.549	0.885	0.478	0.186	1.966	0.408	0.518	1.039
Slovenia	35.299	26.975	0.812	0.561	2.067	1.179	0.528	0.360	2.502	0.915	0.840	0.747
Spain	21.984	16.091	0.878	0.855	1.199	0.632	0.214	0.354	2.029	0.599	0.366	1.064
Sweden	244.646	221.210	0.834	0.466	2.932	2.187	0.114	0.631	4.966	2.999	0.285	1.677
Switzerland	360.747	315.976	2.850	7.271	1.965	1.434	0.050	0.457	3.383	1.780	0.065	1.469
Turkey	1.405	1.081	0.013	0.025	0.943	0.315	0.091	0.537	0.442	0.101	0.047	0.293
United Kingdom	87.214	75.246	1.270	3.932	1.494	0.954	0.199	0.340	3.371	1.495	0.249	1.822
Total	81.068 (98.065)	69.761 (87.537)	1.37 (2.380)	1.569 (2.767)	1.556 (0.666)	0.881 (0.571)	0.303 (0.215)	0.374 (0.179)	2.625 (1.726)	1.202 (1.159)	0.457 (0.338)	0.969 (0.568)

Notes: Data for gross domestic product and research and development expenditure are in PPS at 2000 prices. Standard deviation in brackets. ALL = country level.
Source: Eurostat data

During the period 1994-2009, European average of the number of patents per million of population is 81.068: the maximum value across countries is in Switzerland, and across sectors in the business sector. The North-Western European countries are the most innovative in terms of patenting. In the same period, the European average of R&D intensity is 1.556 and the countries with the highest values are Sweden, Czech Republic and Finland; while generally, the South European countries make the lowest efforts on R&D. From 1994 to 2009, the European average of the number of researchers per thousand population is 2.625. Scandinavian countries and Iceland are the best performers, with values about four or five times higher than the European average.

5. ECONOMETRIC RESULTS

In order to test the importance of international cooperation in FPs on knowledge creation, we specify four models for equation (2). Model (a) represents the basic model with total PKPs (LINK), while model (c) is the basic model with only international PKPs. Model (b) and model (d) integrate model (a) and model (c) respectively, by allowing the impact of total (international) linkages and their interaction with human capital to vary across institutional sectors. Table 3 reports the results of the estimations of the different specifications.

Concerning the choice of the regression model, the statistics of the *patents* variable show the presence of an over-dispersion of the data considered. This result, along with the results of the Wald test based on the parameter of over-dispersion *lnalpha* (which is always significant leading to the rejection of the null hypothesis of absence of dispersion) support the choice of the Negative Binomial regression model.

The empirical analysis gives support to the theoretical framework illustrated in the previous sections. As expected, patents are higher in private companies than universities and research centres (the expected log count for sector *bes* is 2.02 higher than the expected count for sector *gov*). Once controlling for cumulativeness and for differences across sectors in the propensity to patent, consistently with previous analyses (for a review see, Hall et al., 2009), R&D and human capital emerge as important internal drivers of the innovation process.

More interestingly, they influence innovation both separately and jointly showing the importance of taking into account their complementary effect (HP.1). In particular the significance of the interaction coefficients (ρ_1 and ρ_2) show the complex and non-linear nature of the cognitive process, in terms of absorptive capacity.

This result confirms the finding of Charlot et al. (2014) estimating an extended knowledge production function for European regions.

The main value added of this study is the focus on PKPs in international projects as an external innovation driver. The positive and significant coefficient of total public knowledge partnerships in model (a) and (b), and international public knowledge partnerships in model (c) and (d), gives support to the claim that international cooperation between companies, universities and public research centres fosters innovation (HP.2). This result is consistent with previous studies finding that participation in FPs increases R&D spillovers (Maggioni et al. 2007; Hoekman et al. 2013; Di Cagno et al., 2013). Moreover, the results show that the external driver is complementary to domestic human capital (HP.3): in order to reap benefits from international collaboration countries/sectors have to invest in the domestic research community. This fact confirms that the absorptive capacity allows better acquiring and transforming knowledge deriving from collaborations in new patents.

But do private companies, public research centres and universities all benefit from international public knowledge partnerships? And do they benefit equally? The results reported in columns (b) and (d) show that, while all institutional sectors benefit from joint projects, the main benefits (in terms of patenting activity) go to universities and public research centres, while private companies benefit less (HP.4). This is not too surprising considering that firms are by their nature always concerned about the appropriability of the results of the research activity, while universities and public research centres co-operating with firms may be pushed to give more attention to the applicability and commercialization of research activity.

This result is also consistent with the positive impact, emerging in all specifications, of the share of private companies in total participants in FPs on patent applications (HP.5).

Finally, it is interesting to observe that, when looking at differences across sectors, the complementarity between participation in joint projects and internal human capital is stronger for universities than for firms and research centres. Moreover, while in the case of total links a complementary effect between domestic human capital and participation in FPs is found for all institutional sectors, in the case of international links, it is found only for universities.

Table 3 Regression results

	(a)	(b)	(c)	(d)
$(D.Patents)_{t-1}$	1.173***	0.929***	1.194***	0.932***
	(0.113)	(0.129)	(0.114)	(0.129)
Pre-sample fixed effect	0.412***	0.466***	0.419***	0.472***
	(0.0177)	(0.0176)	(0.0178)	(0.0176)
ln(RD)	0.346**	0.695***	0.280*	0.663***
	(0.169)	(0.202)	(0.169)	(0.203)
ln(HUMCAP)	0.281	0.518**	0.337*	0.578**
	(0.203)	(0.232)	(0.205)	(0.231)
ln(LINK_TOTAL)	0.930***	0.543***		
	(0.140)	(0.153)		
ln(POPULATION)	0.295***	0.268***	0.322***	0.289***
	(0.0381)	(0.0395)	(0.0382)	(0.0384)
ln(RD)#ln(HUMCAP)	0.0483***	0.0791***	0.0444**	0.0777***
	(0.0186)	(0.0234)	(0.0184)	(0.0235)
ln(HUMCAP)#ln(LINK_TOTAL)	0.0565***	0.0312*		
	(0.0169)	(0.0183)		
FPs BES weight	0.262***	0.197**	0.266***	0.201**
	(0.0918)	(0.0835)	(0.0918)	(0.0837)
2.dsector_BES	Base	Base	Base	Base
	(.)	(.)	(.)	(.)
3.dsector_GOV	-2.027***	-4.957***	-2.026***	-4.897***
	(0.0955)	(0.340)	(0.0952)	(0.340)
4.dsector_HES	-1.957***	-4.625***	-1.961***	-4.684***
	(0.118)	(0.384)	(0.118)	(0.386)
2.dsector_BES#ln(LINK_TOTAL)		Base		
		(.)		
3.dsector_GOV# ln(LINK_TOTAL)		0.465***		
		(0.0820)		
4.dsector_HES# ln(LINK_TOTAL)		0.647***		
		(0.106)		
2.dsector_BES#ln(HUMCAP)#ln(LINK_TOTAL)		Base		
		(.)		
3.dsector_GOV#ln(HUMCAP)#ln(LINK_TOTAL)		0.0105		
		(0.0111)		
4.dsector_HES#ln(HUMCAP)#ln(LINK_TOTAL)		0.0397**		
		(0.0157)		
ln(LINK_INTER)			0.853***	0.471***
			(0.146)	(0.154)
ln(HUMCAP)#ln(LINK_INTER)			0.0514***	0.0254
			(0.0172)	(0.0182)
2.dsector_BES#ln(LINK_INTER)				Base
				(.)
3.dsector_GOV# ln(LINK_INTER)				0.464***
				(0.0832)
4.dsector_HES#ln(LINK_INTER)				0.658***
				(0.108)
2.dsector_BES#ln(HUMCAP)#ln(LINK_INTER)				Base
				(.)
3.dsector_GOV#ln(HUMCAP)#ln(LINK_INTER)				0.0108
				(0.0111)
4.dsector_HES#ln(HUMCAP)#ln(LINK_INTER)				0.0397**
				(0.0159)
Constant	-3.692***	0.564	-3.645***	0.766
	(1.282)	(1.508)	(1.277)	(1.521)
Lnalpha (Constant)	-0.588***	-0.731***	-0.578***	-0.726***
	(0.0483)	(0.0553)	(0.0479)	(0.0550)
No. observations	1401.000	1401.000	1401.000	1401.000
LR chi2	16699.28	23075.87	16814.26	23141.65
Log Likelihood	-5459.132	-5385.602	-5466.668	-5391.119

legend: * p<.1; ** p<.05; *** p<.01

Notes: Standard errors (in parentheses) are based on the robust variance estimator. Dependent variable is patents. A full set of time dummies for each year are included in all columns. Sets of institutional sectors dummies are jointly significant. Lnalpha is the estimate of the log of the dispersion parameter.

One possible explanation of this result is that the research funded by FPs attracts the best researchers from universities and research and technology organisations (Commission, 2010). For these two non-business sectors, it is particularly important to have a domestic critical mass on which to build effective international co-operations in order to innovate.

Overall, results show that innovation is a process involving three main types of interaction. The first is between internal drivers, notably between human capital and resources for R&D (*internal interaction*), based on their complementarity. The second is among sectors, based on the PKPs, where collaborating actors belong to three dissimilar innovation contexts (*sectorial interaction*). The third is between internal and external drivers, namely between human capital and PKPs, based on the effectiveness of absorptive capacity in converting external knowledge in new knowledge (*external interaction*). In conclusion, according to the empirical estimates, the innovation process analysed is path dependent (depending positively from the past performances), multidimensional (combining different drivers), multiform (involving different players) and not linear (implying multiplicative relationships).

6. CONCLUSIONS

This paper has investigated the role of Public Knowledge Partnerships in international EU Framework Programmes on knowledge creation across R&D institutional sectors (business enterprises, government and higher education). We have argued that FPs are an interesting case of PKPs since they involve at the same time the participation of actors with different objectives and cultures (private companies, universities and public research centres) and belonging to different national systems of innovation.

The results of the empirical estimations point to a positive impact of participation in FPs for knowledge creation (measured in terms of patents) for companies, universities and public research centres. However, when distinguishing across institutional sectors, it emerges how the main enablers, in terms of patenting activity, of such participation are universities, followed by public research centres and private companies. This result, together with the finding that patents increase with the share of private companies on total participants in FPs, suggests that co-operation make universities and public research centres more concerned about the appropriability and possible commercialization of inventions. This may be good for allowing new knowledge to be exploited in industry through the adoption of new processes and the development of new products, with

possible positive effects on productivity and economic growth. At the same time, it raises the concern that intellectual property rights on academic research, by reducing the accessibility of research, may discourage the cumulative process of advancing knowledge by building upon other scientists' ideas (Foray and Lissoni, 2009). However, recent studies suggest that there are complementarities between patenting and scientific performance, and that those individuals that do the best research are also successful at engaging in real world problems and creating commercial value (Rothaermel et al., 2007). Moreover, in most European countries, the main problem still appears to be the low propensity of academic institutions to collaborate with firms and to transform new knowledge into new processes and products. Therefore, the results of this study are encouraging for one of the purposes of private-public collaborations namely that of stimulating the applicability of new ideas to the commercial sphere. What is, however, less encouraging is the decreasing share of firms participating in FPs, starting from FP6. To the extent that this is due to the complicated administrative procedures in the preparation, management and reporting of the project, a simplification of the procedures could encourage a higher rate of participation of companies in FPs with positive knowledge spillovers for universities and research centres. However, this cannot be given for granted since the main precompetitive nature of the FPs makes them more suitable for academic than industrial research (Protogerou et al., 2013). Future studies, possibly distinguishing between different sectors of application of FPs, could better investigate this issue also in order to find the most appropriate mechanisms to stimulate private-public collaborations. Moreover, in order to further contributing to the theoretical debate on the effectiveness of private-public partnerships not only for applied research but also for basic research, future studies could originally integrate the national institutional sectors perspective of this article with regional and spatial approaches, such as Hoekman et al. (2013), that analyses the interrelation between publication activity and FP participation across European regions.

A second important message emerging from this study is that, in order to benefit mostly from participation in EU funded projects, countries have to develop their own internal capabilities. In fact, the higher are the number of domestic researchers, the higher is the impact of international linkages in Framework Programmes for innovation, and this is particularly true in the case of universities. This result has important implications since it suggests that domestic policies devoted to increase the number of researchers particularly in universities are crucial for reaping the benefits of EU R&D policies. Consequently, countries lagging behind in terms of their domestic efforts,

even when obtaining EU funding in international projects, will not be able to compensate their innovation disadvantage in the lack of the necessary absorption capacity.

Finally, this study has also important managerial implications. New knowledge creation is the fruit of complex interactions among different actors (public and private) and innovation drivers (internal and external). Consequently, in order to increase the aggregate benefits of private-public partnerships, it is a major task for knowledge management to make the Science-Technology and Innovation mode (typical of the academic context) and the Doing-Using-Interacting mode appertaining to the business sector work together in promoting knowledge creation (Jensen et al., 2007). The fact that firms appear to benefit less than universities from knowledge partnerships raises the question of whether they lack the necessary managerial capabilities. In particular, the significant complementarity between innovation (R&D) and absorptive capacity (human capital) supports the hypothesis that knowledge management practices might help firms' innovation performance by improving the efficiency of collective learning (Autant-Bernard et al., 2013). At the same time, firms should invest in human capital in order to increase the level of absorptive capacity that favours effective management practises allowing recognising, assimilating and implementing external knowledge by governing the exchange of knowledge flows among co-operating agents (Dunphy et al., 1997; Vega-Jurado et al., 2008).

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